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Technical Support for the Macular Pigment and Visual Performance in Glare

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14. ABSTRACT
The objective of this report is to detail all technical aspects of the 'The Macular Pigment and Visual Performance in Glare' study with respect to software, hardware stimuli generation and stimuli characterization methods.

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1. INTRODUCTION

The Macular Pigment and Visual Performance in Glare study (Brian K. Foutch, O.D., Ph.D., et al [1]) contains three separate parts: a measure of macular pigment, a dietary assessment and disability glare and photo-stress recovery measurement. The objective of the disability glare and photo-stress recovery measurement portions of the study was to determine the effects of macular pigment level based on visual performance in glare conditions. This was accomplished by investigating disability glare in order to determine a person's ability to correctly identify a Gabor patch orientation obscured by glare as well as photo-stress recovery time, the time needed to reacquire and correctly identify a target after exposure to a brief, intense flash of light. The glare source exposures were delivered via two high bright LED's (Light Emitting Diodes).

The focus of this technical report is not to describe the biological aspects of macular pigment or the results of this particular study, but instead to document software operation, hardware interfacing, stimuli generation and spatial characterization, along with photometric calibration methods necessary that supported Part III of the study.

2. METHODS

2.1 Software Operational Overview

A Visual Stimulus Generator, model VSG2/5 (Cambridge Research Systems, Ltd., Rochester, Kent, England). was used to generate a custom Gabor patch (a Gaussian-windowed, sinusoidal luminance pattern) which served as the visual stimuli for both portions of the study. The VSG system easily creates a wide variety of custom 2D visual stimuli for a variety of software platforms. For this study, the VSG system was programmed using National Instruments LabVIEW™ (Laboratory Virtual Instrumentation Engineering Workbench) software and the CRS Toolbox for MATLAB® (Cambridge Research Systems, Ltd., Rochester, Kent, England).

The use of the CRS Toolbox enables the user to write script nodes to draw custom visual stimuli with parameters that can be easily changed "on-the-fly" within the LabVIEW™ environment, cuts down on the amount of source code which needs to be developed for custom stimuli generation, and provides the programmer with a more flexible software interfacing environment to accomplish instrumentation control, data collection and complex subject tasks. There are three main functional areas that the software development supports: photo-stress testing, disability glare testing and photometric calibration of test contrast levels. Section 2.4 provides more detail regarding stimuli generation.

2.2 Photo-Stress Software and Hardware Operation

The photo-stress study required subjects to view a high bright LED glare stimulus directly for a short time period 2-s. Next, the subject would attempt to detect and identify a Gabor patch orientation angle (45^o or -45^o) for a series of targets with reducing contrast levels. The time it took the subject to identify the Gabor patch orientation correctly at each level of contrast, was considered to be their threshold visual performance for the photo-stress recovery task. The orientation of the Gabor targets was also randomized for each trial. This portion of the experiment utilized two mean background luminance test levels during testing: 5cd/m^2 and 27cd/m^2 and two spatial frequencies: 5 and 12 CPD (cycles/degree). Pertinent data recorded included: subject responses, spatial frequency, test contrast level, Gabor angular orientation, and reaction times were recorded.

Photo-stress testing was performed binocularly using two overlapped LED exposures as the main glare source during the task. Software for this task was written in LabVIEW™ with MATLAB® script nodes in order to pass variables to the Gabor function so that parameters such as contrast level, orientation angle, spatial frequency and standard deviation could be changed "on the fly" during the testing.

Figure 1 below shows the photo-stress experimental setup. The viewing distance from the subject's eye position to the center of the viewing screen was measured to be 242.57 cm (95.5 in) and resulted in a Gabor patch diameter which subtended 1.19^o of visual angle at the eye. A set of optics were used at the eye position to ensure that the glare sources were brought into the eyes at a 5^o FOV (field of view).

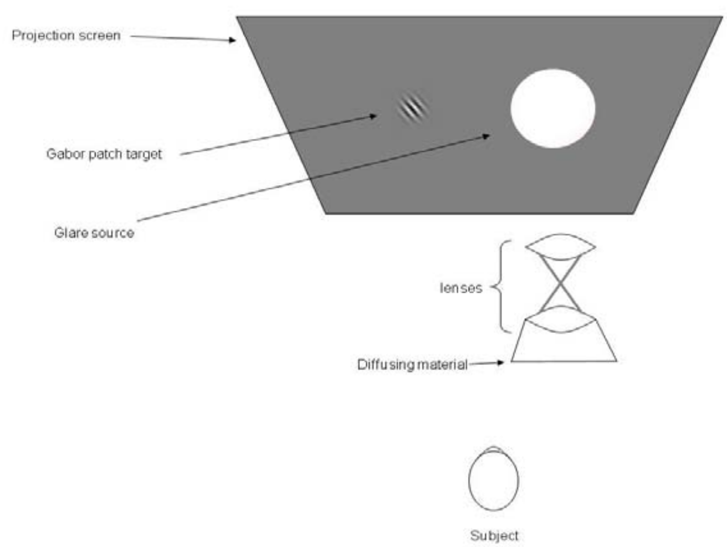

Figure 1: Photo-stress experimental setup

Before the start of the experiment, each subjects' IPD (interpupillary distance - the distance between the centers of the pupils) were measured with a Digital PD Meter (Burton LLD, Drive Grove City, OH). The purpose of this measurement was to ensure that each LED source could be properly aligned to the subject's eye position. Each of the LED's was mounted onto a linear stage with an adjustable base in order to compensate for any angular corrections needed to align with the eyes. A 5^o FOV alignment target was also drawn at the center of the screen where the presentation target was to be visually located. The subject aligned themselves to both LED's by adjusting each linear stage until the positions appeared to be visually overlapping within the 5^o FOV circle. This alignment technique ensured that the LED intensity was maximally distributed across both pupils during the task.

2.3 Disability Glare Software and Hardware Operation

Similar to the photo-stress software development, the disability glare test was also written in LabVIEW™ with the use of MATLAB® script nodes for Gabor patch generation. The purpose of this study was to have the subject correctly identify the orientation of the Gabor patch during the LED exposures while responding to different contrast levels generated by a staircase algorithm. Unlike the photo-stress task which used visually overlapped LED sources at the eye position, this task required each LED to be visually separated by 5^{o} from either side of the Gabor target with respect to the subjects' eye position. The subjects were aligned as done in the photo-stress task, with the exception of the separation of the two LED sources. Figure 2 shows the disability glare experimental setup.

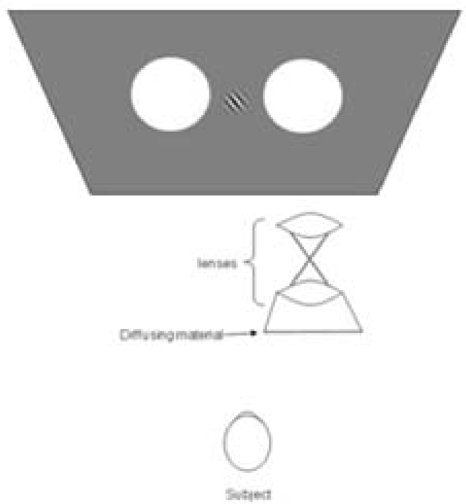

Figure 2: Disability glare experimental setup

The disability glare task consisted of 25 trials and required the subject to respond within a 2-s window while exposed to the LED glare sources. A correct response was generated when the subject was able to correctly identify the orientation of the Gabor patch through the glare source. An incorrect response was generated if the 2-s timeout elapsed or if the subject incorrectly identified the Gabor patch orientation. An incorrect response indicated a 2-s time-out condition or an incorrect button response. An ascending/descending method of limits staircase algorithm was written in order to quickly and effectively determine the subject's contrast threshold during the testing sequence. Subject response determined whether the staircase algorithm incremented or decremented the percent contrast level. A correct response lowered the contrast level by a predetermined amount and an incorrect response increased the contrast level by a predetermined amount. A snapshot of the staircase algorithm testing sequence is shown in Figure 3 on the next page.

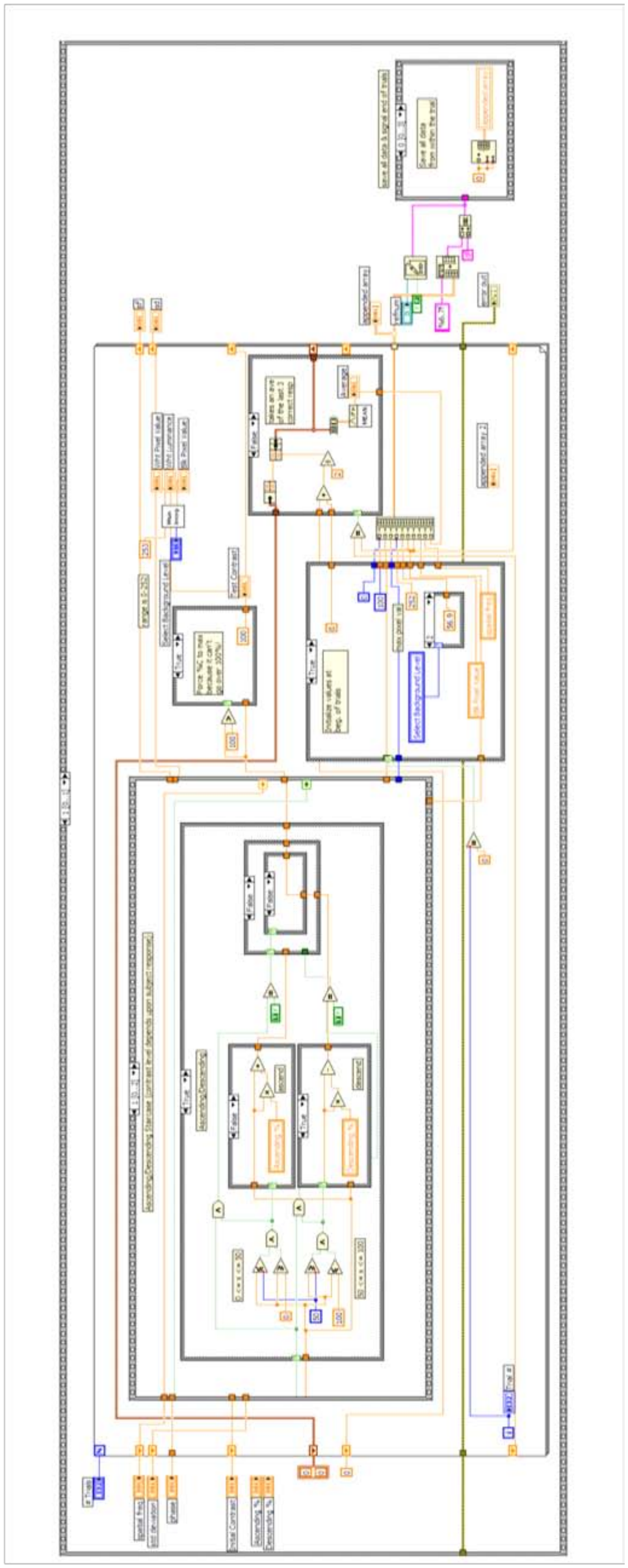

Figure 3. Staircase algorithm testing sequence

At the end of the twenty-five trials, an average of the last three correct responses provided the final contrast threshold value. The subjective contrast threshold value among subjects varied anywhere from .6 to 2.6 cd/m^2. Pertinent data recorded include: subject responses, spatial frequency test contrast level, Gabor angular orientation, and reaction times were recorded and a final contrast threshold value.

2.4 Stimulus Generation and Spatial Characterization

The Gabor patch stimulus was generated via a VSG2/5 system with an 8 bit framestore and 15 bit output resolution (luminance and color). The VSG2/5 has a dedicated on-board processor for high-speed LUT animation, a TMS34020, 50MHz graphics processor and software API for 32 bit windows [3]. Full resolution is accessed by values that are loaded into the palette, i.e., pixel levels used to define the stimuli. These are indexed into a LUT (Look Up Table) which provide 8 bit in, 14 bits out. In other words, each 0-255 pixel level looks up a corresponding 3x15-bit RGB value to display.

A Gabor patch (defined as a sinusoidal grating windowed by a two dimensional Gaussian function) was used as the main stimulus for the photo-stress and disability glare tasks. MATLAB® script nodes were used to generate the Gabor stimulus patch via CRS Object Animation functions. An initialization script node first performs the following processes: loads all CRS global constants from the VSG.DLL version 1.26, initializes the VSG graphics card, sets up the RGB levels for controlling the contrast and background levels of the defined object, sets the Gabor color vector (to ensure that the contrast varies about a mean background luminance), defines the object size (in pixels) and sets up and calls the Gabor patch LUT (look up table) parameters. The space-time luminance function of a Gabor patch is defined by Fredericksen et al [2] and has the general form:

$$L(x,y,t) = L_m\left\{1 + C_p \cos[2\pi x f_c]\exp\left[-\frac{1}{2}\left(\frac{x}{\sigma_x}\right)^2 - \frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\right\} \qquad \text{Equation (1)}$$

The mean background luminance is represented by the term L_m, peak contrast of the Gabor is represented by C_p, x and y represent both horizontal and vertical position in space, f_c represents the carrier frequency (frequency of oscillation) of the sinusoidal grating, σ_x and σ_y represent the standard deviations (full width at half height of horizontal and vertical Gaussian) of the spatial gaussian window. The contrast level of the Gabor is determined by using the CRS.BIPOLAR color mode which ensures that the Gabor function uses the mid-level background (which is half way between the function extrema). The Gabor patch is defined in Equation (1) and drawn by the VSG2/5 using the following function:

```
CrsDrawGabor (GaborLocation, GaborSize, GaborAngle, GaborFrequency, GaborDeviation, GaborPhase);
```

The parameters listed in the above function have the following specifications: GaborLocation specifies horizontal and vertical position, GaborSize is used to set the width and height of the box that the Gabor patch is drawn within, GaborAngle determines the orientation (or angular tilt) in degrees, GaborFrequency is the spatial frequency specified in cycles per pixel or cycles per degree, the GaborDeviation of the Gaussian envelope defines the patch size and GaborPhase is used to determine the phase shift of the sine grating.

Gabor patch contrast levels and spatial distributions used in this study were all drawn within a 2” x 2” window and characterized by use of a PR-920 digital photometer (Photo Research Inc., Chatsworth, CA), a 60-mm objective lens and VideoWin™ software. The PR-920 is a thermoelectrically cooled, 16-bit high spatial resolution camera consisting of 1024 x 1024 pixels, for a total of 1.048 million pixels. Figure 4 shows a luminance profile of the 5 CPD, 100% contrast Gabor patch generated by the VideoWin™ software. The zoomed-in perspective in this figure shows the 5x5 mm AOR’s (Area of Regard) for the peak (white bar) and trough (black bar) of the Gabor stimulus. The minimum and maximum luminance measurements represent an average luminance of all the pixels located within each respective AOR. The software also captured and exported all pixel luminance values to Microsoft Excel® for further data analysis.

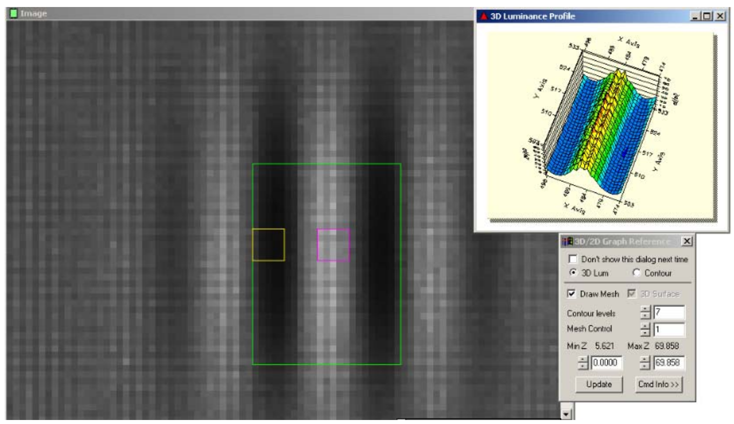

Figure 4: 5 CPD luminance profile with zoomed AOR pixel levels

All test contrast percentage levels used for testing were verified from all imported PR-920 Excel spreadsheet data and calculated using the following contrast formula:

$$\%Contrast = \frac{(Peak - Average)}{Average} \times 100 \qquad \text{Equation (2)}$$

The Gabor patch was projected onto a 50" H x 67" W CSR Glass Beaded Surface "Model C" projection screen (Da-Lite Screen Company, Warsaw, IN) using an NEC LT380 (NEC Display Solutions of America, Portola, CA) projector with a resolution of 1024 x 768. The display was set to the high-bright mode with a brightness setting of 10 and a contrast setting of 50. The projector zoom, which is rated at 1.20:1, was minimized in order to shrink down the pixel size of the Gabor patch to a 1.19^{o} patch size. Figure 5 shows the luminance profiles of the 5 CPD Gabor patch.

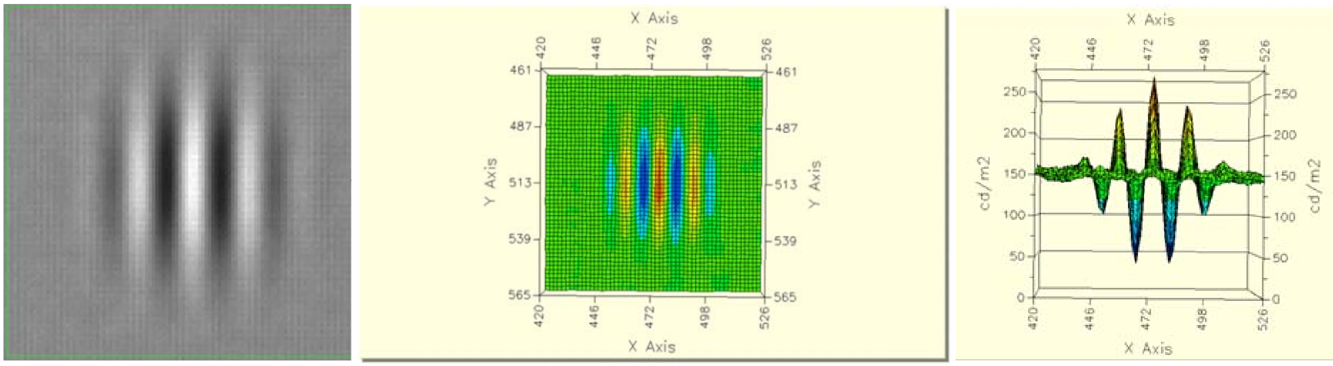

Figure 5: Luminance profiles of the 5 CPD Gabor patch

Figure 6 shows the luminance profile of the 12 CPD Gabor patch with AOR's located on the peak and trough during average luminance measurements.

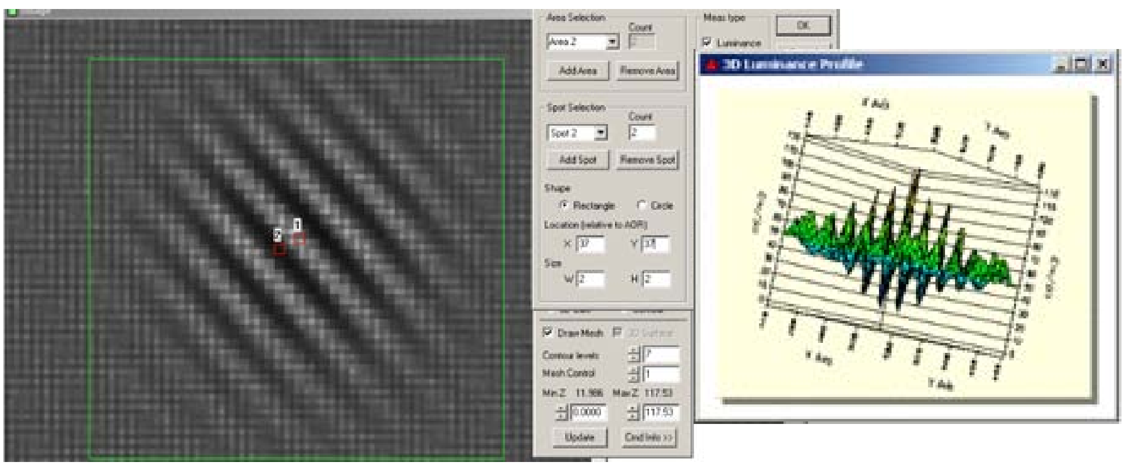

Figure 6: Luminance profiles of the 12 CPD Gabor patch

2.5 Photometric Calibration Measurements

Photometric calibration measurements were performed at the eye position using a LS110 hand held photometer (Konica Minolta, Grand Rapids, MI) in order to verify all presentation contrast levels and individual pixel level luminance values used to generate the contrast levels during the photo-stress and disability glare tasks. All contrast values were also cross-calibrated with the model PR-920 digital video photometer (Photo Research, Chatsworth, CA) to ensure that all measurements were consistent. The mean background had two operational luminance levels, a low level of 5cd/m^2 and a high level of 27cd/m^2. The highest background level was initially set by changing the projector brightness and contrast levels to achieve the desired 27cd/m^2. The desired low background level of 5cd/m^2 was achieved using the higher background setting along with a combination of neutral density filters placed in front of the projector lens.

Separate screen calibrations were performed in order to determine the luminance values for each background level. A LabVIEW™ program was written to generate pixel level luminance values for each of the background levels. A 2” x 2” calibration square was drawn onto the center of the screen and subdivided into two halves. Either side of the calibration square could be used to change pixel steps from 1 to 255 in order to perform luminance measurements and to verify contrast levels. Figure 7 shows the luminance profiles of the calibration square taken with the PR-920, displaying the maximum and minimum luminance levels generated by the program.

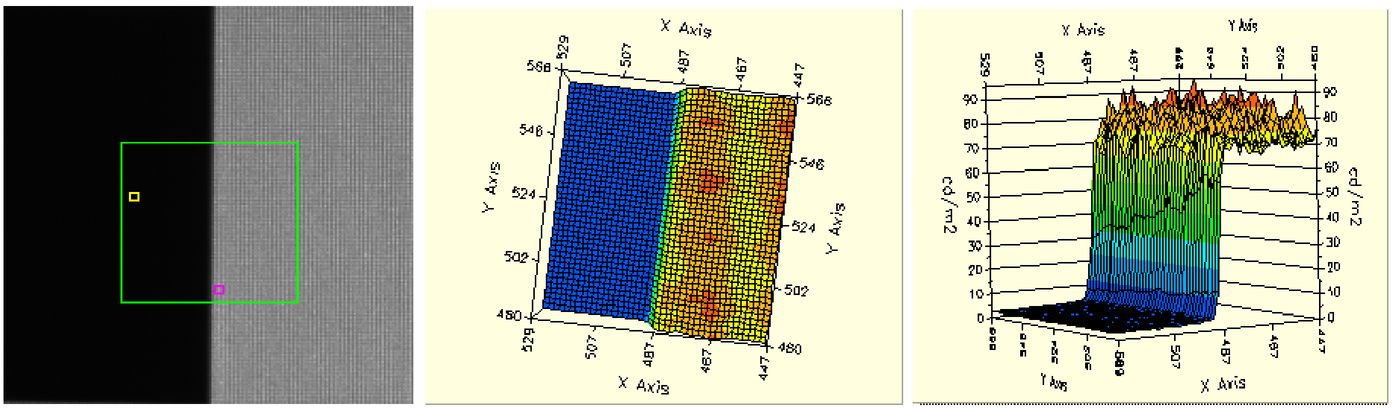

Figure 7: Luminance profiles of contrast calibration square with AOR’s

The maximum contrast percentage used during the tasks was calculated from measured values using Equation (2) to be 85.6%. A LabVIEW™ program was written using Bilinear Interpolation methods for referencing the appropriate calibration data associated with both background levels. This data provided the appropriate pixel values for displaying specific levels determined by the staircase algorithm during the task. Gamma correction curves for both background luminance levels used in the study are shown in Figure 8 on the next page.

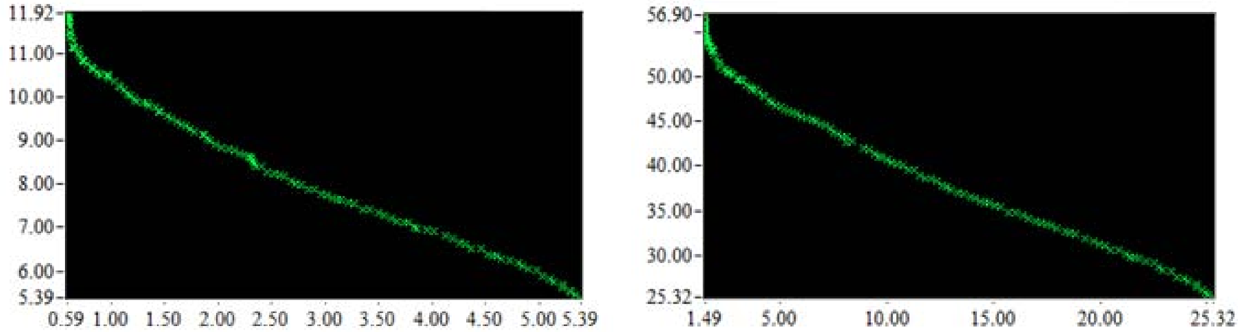

Figure 8: Gamma correction curves for background luminance levels

2.6 LED Characterization

Both tasks used two White Luxeon® V Portable Star (Phillips Lumiled, San Jose, California) cool white LED's as the glare sources. All LED exposures were controlled from an NI-DAQmx (a National Instruments data acquisition driver), LabVIEW™ software by use of a PCI-6024E DAQ (Data Acquisition). The LED's were pulsed on and off via PWM (Pulse Width Modulation) for a total of 2s before the presentation of the randomly oriented Gabor patch was presented. PWM was used to effectively control the pulse width and duty cycle of the LED to provide the necessary luminance level during the task. All LED exposures used during the tasks used a duty cycle set to a total on-time of 50% at a modulating frequency of 1000 Hz, which provided a luminance level of 10,000 cd/m^2 per LED. Before either task was started, an alignment routine set the duty cycle to 1% to decrease the LED forward current. This lowered intensity allowed the subject to better align their eyes with the black alignment target located on the screen.

A discrete component LED driver circuit, shown below in Figure 9 on the next page, was built in order to pulse the LED on and off for set exposure durations during both visual tasks. The driver circuit was necessary because the PCI-6024E DAQ card was not capable of producing the necessary 700-mA current to drive the LED.

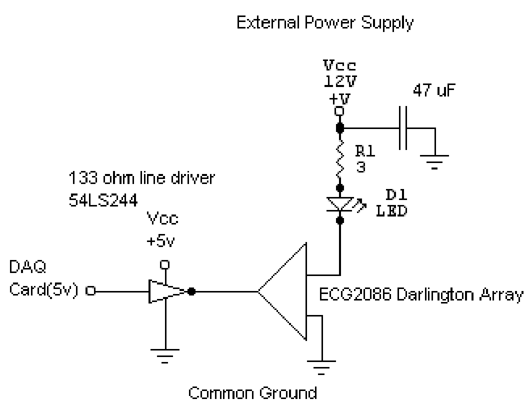

Figure 9: Luxeon® D-6500 LED driver circuit

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The circuit consists of a 2N2222 Darlington pair current amplifier, an ECG 181 line driver, a 3-ohm ceramic pull-up resistor and a 47uF filter capacitor. A program was written to generate a 5V square wave output signal from the 24-bit counter pin on the PCI-6024E DAQ board. This voltage was used to pulse the circuit on/off at the desired duty cycles during alignments and tasks.

Each of the LED's used in this study were characterized by use of a USB 2000 spectrometer (Ocean Optics, Dunedin, Florida) with a 2048-element linear silicon CCD array and OOIBase32™ (32-bit software) spectrometer operating software. The effective range of the spectrometer is between 200 – 1100nm with a dynamic range of 2 – 10s. The duty cycle in the PWM software was lowered to 1% in order to characterize the output of the LED's. The broadband spectral output measurement can be seen below in Figure 10, with a main peak at 446.01nm and 1116 intensity counts (relative irradiance spectra) on the y-axis. Both LED's were both measured to ensure that their main peaks closely matched the light testing source of a device used in measurements of MPOD (Macular Pigment Optical Density) made prior to the photo-stress and disability glare testing. For information regarding the MPOD measurement device and technique, please reference [4].

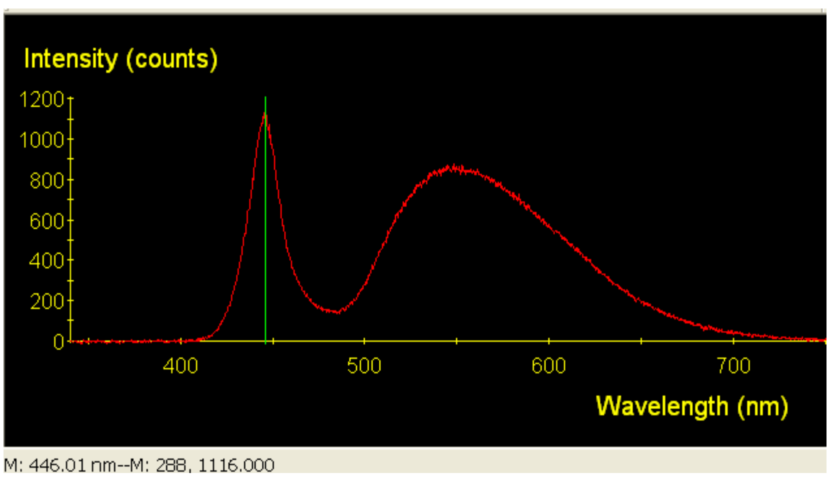

Figure 10: Luxeon® D-6500 LED spectral response

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